Reducing Environmental Risk Associated with Laboratory Decommissioning and Property Transfer

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The need for more or less space is a common laboratory problem. Solutions may include renovating existing space, leaving or demolishing old space, or acquiring new space or property for building. All of these options carry potential environmental risk. Such risk can be the result of activities related to the laboratory facility or property (e.g., asbestos, underground storage tanks, lead paint), or the research associated with it (e.g., radioactive, microbiological, and chemical contamination). Regardless of the option chosen to solve the space problem, the potential environmental risk must be mitigated and the laboratory space and/or property must be decommissioned or rendered safe prior to any renovation, demolition, or property transfer activities. Not mitigating the environmental risk through a decommissioning process can incur significant financial liability for any costs associated with future decommissioning cleanup activities. Out of necessity, a functioning system, environmental due diligence auditing, has evolved over time to assess environmental risk and reduce associated financial liability. This system involves a 4-phase approach to identify, document, manage, and clean up areas of environmental concern or liability, including contamination. Environmental due diligence auditing includes *a*) historical site assessment, *b*) characterization assessment, *c*) remedial effort and *d*) final status survey. General practice standards from the American Society for Testing and Materials are available for conducting the first two phases. However, standards have not yet been developed for conducting the third and final phases of the environmental due diligence auditing process. Individuals involved in laboratory decommissioning work in the biomedical research industry consider this a key weakness. *Key words:* assessment, characterization, decommissioning, decontamination, demolition, environmental, laboratory, liability, remediation, renovation. — *Environ Health Perspect* 108(suppl 6):1015–1022 (2000). *http://ehpnet1.niehs.nih.gov/docs/2000/suppl-6/1015-1022dufault/abstract.html*

There are a number of different types of laboratories used by scientists and organizations to conduct research activities. The types of activities to be conducted and the hazardous substances to be used generally determine laboratory space requirements. Space requirements to be considered are heating, ventilation, and air-conditioning systems and laboratory layout, including the number and sizes of laboratory chemical hoods; availability of change, decontamination, and shower rooms and hand-washing sinks; fire protection systems; structural loads; and egress routes. Depending on the mission of the organization and the subsequent activities to be conducted, sometimes there are additional requirements for support spaces such as animal care, cold storage, autopsy, and dark rooms. When the mission of the organization changes, space requirements often change as well. The need for more or less space is a common laboratory problem. Solutions include renovating existing space, leaving or demolishing old space, or acquiring new space. Regardless of the solution, laboratory space must be decommissioned or rendered safe prior to renovation, transfer, or demolition. This should be done in a manner consistent with pollution prevention and waste minimization techniques.

Although this article is directed primarily at the laboratory decommissioning process, we would be remiss if we did not stress prevention techniques. The use of good laboratory practice can eliminate or at least reduce the extent of contamination that will need to be addressed at some future time (*1*).

It is not always necessary, or even desirable, to completely decontaminate/decommission a laboratory before transfer, renovation, or demolition. The decision on the level of decommissioning needed should take several factors into consideration: *a*) type of contaminants present and associated risks, *b*) nature of planned renovation activities, *c*) intended use and level of controls after transfer, *d*) possibility of reclaiming or recycling contaminated debris, *e*) regulatory requirements, and *f*) costs associated with decontamination versus removal and disposal of materials debris without the contamination.

Decommissioning or Acquiring Space: An Environmental Liability

There can be environmental risk associated with renovating, leaving, and demolishing old laboratory space or acquiring new space. Environmental risk can be the result of activities related to the facility (e.g., materials from construction or maintenance activities) or related to the research activities (e.g., use of hazardous substances) and includes the risk to personnel who perform the renovation, demolition, or decommissioning cleanup activities. If an organization leaves a laboratory contaminated, future liability equal to or greater than costs associated with decommissioning cleanup activities may be incurred by that organization. If, on the other hand, the organization acquires a contaminated laboratory property, ownership requires cleanup at some point. With regard to acquisition of contaminated property, the law is clearly stated in section 9601 (35)(B) of Code of Federal Regulations Title 42 (CFR 42) (*2*). The new owner of the property is liable for the cleanup costs associated with contamination of the property if he/she has not "undertaken at the time of acquisition, all appropriate inquiry into the previous ownership and uses of the property consistent with good commercial or customary practice." An organization is wise, then, to undertake this appropriate inquiry before acquiring laboratory property to minimize any liability should environmental contamination be found at a later date. The law, unfortunately, does not define what level of inquiry is appropriate. Out of necessity, a functioning system of inquiry has evolved over time and this system is used extensively by the banking industry

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and others involved in property transfer transactions. This system, environmental due diligence auditing, involves a 4-phase approach to identify, document, manage, and clean up areas of environmental concern or liability, including contamination, prior to property transfer. Organizations commonly use this approach to minimize environmental risk associated with leaving and decommissioning an old property or acquiring a new laboratory space or property. The American Society for Testing and Materials (ASTM) has developed two general practice standards that provide guidance for conducting the first two phases of the environmental due diligence auditing process (*3*,*4*). Standards have not yet been developed, however, for the third and final phases of the process, and this is considered a weakness in the property transfer industry.

Phase I: Historical Site Assessment

The first phase of the environmental due diligence auditing process is undertaken to identify potential areas of environmental concern, including contamination, or future liability. Areas of environmental concern or liability usually arise from historical or current uses of hazardous substances. Hazardous substance use or applications are common in laboratory operations as well as in building and property maintenance. Tracking various applications of hazardous substances in the laboratory can identify potential areas of environmental concern or liability. Four procedures are conducted during the historical site assessment to track various uses of hazardous substances in the laboratory or within the building or boundaries of the property. These procedures include

- Interviews with the current property owner, manager or lessor, local government officials, and laboratory personnel to obtain as much information as possible about the property itself and the laboratory operation and activities. Included in this inquiry would be past and present environmental practices, facility improvements or alterations, building/property operations and maintenance, and plans for future use.
- A review of the applicable documents and records to determine if any information is available, either at the laboratory facility or via public records, regarding potential environmental contamination resulting from laboratory operations or other activities conducted at the facility or property.
- A site visit or inspection to observe the current uses (and past uses, whenever possible) of the property, including those likely to involve the use, treatment, storage, disposal, or generation of hazardous substances, such as petroleum products.
- A written report to document Phase I findings, observations, and recommendations, including suspected or identified areas of environmental concern or liability and what, if any, Phase II sampling and analyses activities should be conducted to verify the suspected areas of contamination.

The written report is an important document, as it should demonstrate that appropriate inquiry was undertaken to ascertain ownership and uses of the property prior to acquisition. This appropriate inquiry should minimize any future liability in the event that environmental contamination is found on the property after acquisition. Specifically, the results of the historical site assessment should document either one of the following determinations: *a*) the potential for contamination exists and a Phase II characterization assessment is recommended to evaluate this potential prior to property transfer, or *b*) there is no potential for contamination and the property may undergo transfer without additional assessment.

With regard to laboratory closure, the report will provide direction for necessary decommissioning activities. Once Phase I procedures are complete, it is important to provide a copy of the written report to all relevant parties, including the owner and/or lessor and pertinent laboratory personnel. It may be necessary to provide a copy of the report to the appropriate Federal, state, and local agencies.

Phase II: Characterization Assessment

Potential areas of concern or contamination identified in the Phase I report are evaluated during the second phase of the environmental due diligence process. Specifically, a potential contaminant(s) of concern is identified along with the applicable cleanup or release criteria. A sampling and analyses strategy is then developed so that sufficient data can be obtained to allow a designated individual to conclude that *a*) the contaminant of concern is present at levels above the cleanup or release criteria and a remedial effort is necessary, or *b*) the contaminant of concern is present at levels below the cleanup or release criteria and no further action is required, or *c*) the contaminant of concern is not present and no further action is required.

The sampling and analyses strategy should also provide sufficient data to characterize the extent of contamination if the contaminant of concern is present at levels above the cleanup criteria.

Characterization Assessment Considerations

Scope of work/sampling and analysis plan. A qualified individual shall develop a scope of work with a series of tasks that will fulfill the objective(s) of the Phase II assessment. The sampling and analysis plan, or SAP, should include a justification for each screening method to be used and each sample location; a discussion of the quality assurance (QA)/quality control (QC) measures to be taken to ensure sample integrity (e.g., appropriate labeling, handling, preservation, chain of custody, and documentation); and a discussion on the measures to be taken to ensure personnel health and safety.

Assessment procedures. The assessment may include field screening techniques using direct reading instruments (e.g., Geiger-Mueller meters for radiation or X-ray fluorescence meters for lead), destructive sampling techniques, and environmental media sampling (e.g., air, water, surfaces). Examples include surface wipes for toxic solid materials such as radiation or metals (e.g., organic or inorganic mercury compounds) and liquid samples from plumbing systems. Field screening techniques (e.g., collection of bulk samples, visual inspection, air sampling, surface wipe tests) are particularly useful for guiding the collection of samples such as acrylamide for more detailed laboratory analysis.

Data review. The analysis data must be reviewed to determine if they are of sufficient quality to confirm the presence or absence of a contaminant of concern. The basis for the sampling plan should be reexamined using any information obtained during the assessment to ensure that the initial assumptions are still correct. Finally, the QA/QC program for all sampling and analysis should be reviewed to ensure that any positive samples are not attributable to sample analysis error.

Findings/results. The significance of the results of the sampling data depends upon whether the contaminant is present and a hazard or unreasonable risk to human health and the environment exists. It should be possible to determine the significance of the findings by comparing the level of contaminant measured with an existing regulatory or industry cleanup standard [e.g., U.S. Environmental Protection Agency (EPA) debris standard, U.S. Nuclear Regulatory Commission (NRC) license termination limits, National Pollutant Discharge Elimination System effluent standards]. All findings, significant or not, and recommendations, including whether remediation is necessary, should be documented in a Phase II report.

At the conclusion of the Phase II assessment, the status of the laboratory property should be clear. A determination will have been made as to whether it is free of the identified contaminant(s) of concern or contaminated, with or without remediation necessary. The Phase II report can be used to direct the implementation of the Phase III remediation actions.

Phase III: Remedial Effort

If the laboratory property is contaminated with a hazardous substance(s) and the Phase II assessment determines that it presents an unreasonable risk to human health or the environment, a remedial effort must be made to decontaminate the area(s) of concern. This effort will reduce or eliminate future liability for cleanup and assure that future uses of the laboratory will not result in unreasonable risk to human health and the environment from the contaminant of concern. As there is no industry standard or guidance for this phase of the due diligence process, a literature search must be conducted to find the appropriate decontamination method and procedures necessary for the remedial effort. The selection of the decontamination method and procedures will depend on the nature of the contamination (radiation, microbiological, chemical), the specific contaminant, and the contaminated surface (impervious vs porous, and structural vs nonstructural). The NRC has authority over radioactive materials and any radiation contamination resulting from their use (*5*). Suggested methods for microbiological decontamination are provided by Edwards et al. (*6*). Decontamination will not be successful if the cleanup criteria are not met. Possible decontamination methods and procedures include

- Complete removal: the contaminated surface/structure is completely removed intact for disposal. Example: asbestos-containing materials.
- Stripping: the contaminant is removed from the surface by stripping off a thin layer. Example: lead paint or radiation, using scabbling devices or similar tools.
- Cleaning: the surface is washed or wet wiped with an appropriate solvent, or contaminants are removed by vacuuming, scraping, or brushing. Example: acrylamide powder can be HEPA (high-efficiency particulate air filter [a dry filter consisting of fibers]) vacuumed or wet wiped.
- Disinfecting: the surface is washed with a disinfectant that kills or deactivates the agents. In the case of biological agents, the Association for Professionals in Infection Control and Epidemiology, Inc. has developed a practice standard for selection and use of disinfectants (*7*).

A decontamination plan should be prepared once the decontamination method is selected and the appropriate work procedures are established. A field screening method for measuring the effectiveness of the decontamination method should be included. The decontamination plan should address issues such as isolation of the work area, protection of uncontaminated surfaces and equipment, and protection of the workers by using appropriate work practices and personal protective equipment (PPE). After the plan has been implemented, the decontamination method and procedures must be documented in a Phase III report. Prior to property transfer, renovation, or demolition, a final status survey should be performed to confirm that cleanup was achieved and the remedial effort was a success.

Phase IV: Final Status Survey

Phase IV of this process is to document the final conditions of the space/property after remediation has been completed. For a remedial effort involving radioactive contamination, the U.S. Department of Energy has developed a certification protocol, the Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM), that details all of the steps necessary to fully document the final status of a decommissioned or clean laboratory facility (*5,6*). There is no industry standard or guidance, however, for conducting final status surveys for remedial efforts involving chemical contamination of surfaces or equipment. In this case, the due diligence process usually ends after the remedial effort is documented in the Phase III report. In practice, this report is the end of a paper trail that documents that appropriate inquiry and action were undertaken to identify, manage, and remediate all areas of chemical contamination. Although this paper trail is then used as a basis for the final property transfer agreement or to initiate renovation or demolition, there may be additional terms or conditions that must be met. In private industry, the final property transfer agreement or settlement will be reached only with the blessing of the lender, who will base its decision on the buyer's intended use of the property. For example, if a buyer wishes to purchase a laboratory facility with potential mercury contamination in the pipes, it may do so as long as it intends to use the facility as a laboratory. If a buyer wishes to purchase a laboratory facility with potential mercury contamination in the pipes for the sole intention of demolishing it and building a parking lot in its place, the lender may not readily finance the purchase without a significant decrease in price to compensate for cleanup costs. It is understood that the new owner (buyer) will assume all future environmental liabilities associated with hazardous substance use, both past and present. Contrary to private industry practices, a Federal agency never transfers its environmental liability upon property transfer. The owning Federal agency must document on the deed or lease that hazardous substances were used and/or released on the site. The agency must also warrant that all remedial action necessary to protect human health and the environment with respect to the hazardous substances was taken and any additional remedial action found to be necessary after the date of property transfer shall be conducted by the United States (*8*).

Several practical examples are provided in the appendices.

Conclusion

It should be clear that there is a need to develop general practice standards for Phase III and Phase IV of the due diligence laboratory decommissioning process. A survey of industry-specific laboratory decommissioning issues (e.g., pharmaceutical, chemistry, biotechnology, university, semiconductor, and hospital) should be conducted to identify the best available remediation technologies for specific contaminants of concern. Once the technologies are identified, they could be included in the Phase III general practice standards. In addition, because current practices do not assure cleanup or successful remediation, there is a need to develop general practice standards for conducting a Phase IV final status survey. Ideally, the purpose of a final status survey would be to collect and analyze samples in a number sufficient to statistically confirm that the cleanup criteria were met and the remedial effort was a success. The MARSSIM is a Federal agency consensus document that could be used as a reference guide for developing and conducting this type of survey (*5*).

To illustrate how the due diligence laboratory decommissioning process works, we provide appendices with the following case history examples. These examples are composite case studies and do not represent one specific case: 1) perchloric salt contamination in laboratory chemical hoods, 2) ^{14}C radionuclide contamination, 3) ^{3}H, ^{14}C, and ^{125}I radionuclide contamination, 4) arsenic contamination, 5) mercury contamination in plumbing system (theoretical), and 6) hazardous substances in hood ductwork.

Appendices

Appendix 1. Perchloric Acid Salt Contamination in Laboratory Chemical Hoods

Phase I: Historical Site Assessment

After a new research laboratory facility was built to consolidate several old stand-alone labs into one modern state-of-the-art complex, the agency decided to dismantle the old labs and demolish the buildings.

Many environmental and safety concerns were identified during the initial site assessment. Of particular concern in one of the old labs was the possibility that perchloric acid was used at elevated temperatures in the laboratory hood. The problem was that

the hood was not approved for perchloric acid. When used in a vent system without internal washdown capability, perchloric acid salts become deposited in the hood, baffles, filters, fans, ducts, and exhaust stacks. If this were the case for this particular hood, the question would be how many other laboratory hoods had been used for perchloric acid procedures.

The use of perchloric acid was preferred in laboratory procedures such as digestion of biological tissues, as it offered desirable properties of mineral acids without introducing ions that often interfered with other chemical reactions. Unknown to the researcher, when the perchloric acid vapors condensed and reacted with other substances, it left behind potentially dangerous perchloric acid salt particles in the ductwork. These perchloric acid salts can be highly explosive when subjected to heat or shock.

Through interviews with other researchers it was determined that more chemical hood vent systems were potentially contaminated with perchloric acid salts.

Phase II: Characterization Assessment

A sampling protocol needed to be established and it was determined that as there were only five laboratories with chemical hoods in them, all hoods would be tested.

Before any testing was performed, workers were trained on the hazards that could be encountered, and PPE consisting of gloves and eye protection was issued.

An examination of the analytical chemical literature for perchlorates revealed few tests specific for perchlorates or perchloric acid. An analytical reagent that comes close to satisfying these criteria is methylene blue. It is frequently used for both qualitative and quantitative determination of perchlorates. Methylene blue forms a violet precipitate with perchlorate ions. It was determined from all literature available that a 0.3% aqueous solution of methylene blue gives satisfactory results. Precautions associated with the use of this solution were published in a recent journal article (*9*).

Small areas near the ductwork and fan of each hood were washed down with water, the liquid rinsate was contained, and a few drops of the test solution were added. A methylene blue test is similar in principle to a litmus test. If perchlorates are present, the test solution produces a violet precipitate. If the results of the methylene blue test were negative, at least two more areas (preferably accessible areas in the ductwork) were washed down and tested before the hood was determined to be perchlorate-free.

Through testing, it was discovered that two additional hoods required decontamination for perchlorates.

Phase III: Remedial Effort

Prior to dismantling of the hoods, additional training was provided to the remediation crew, and specialized protective gear was issued. Workers who took part in the dismantling process donned ballistic gear similar to that used by bomb squad personnel.

As perchlorates are not generally a problem if kept wet, the key to the dismantling process was to keep everything wet. Workers simply sprayed the hoods and other vent system components with water. Fiberoptic scopes were used to ensure that confined areas such as those behind hood baffles were wetted down. All the washdown water was contained for proper disposal.

While keeping the components of the hoods and vent systems wet, workers carefully dismantled all parts and moved them to an area set up for thorough decontamination. Rinsate was contained, and all that tested positive for perchlorates was disposed of by an approved hazardous waste contractor.

It is important to note that even though the remaining hoods and vent systems were determined to be perchlorate-free, special care was taken in their dismantling process.

Phase IV: Final Status Survey

In the absence of information on this particular situation, the MARSSIM approach was used to accomplish a final status survey.

Documentation of the procedures used for testing and dismantling of the hood and duct systems as well as for proper disposal procedures was provided to agency laboratories that might encounter similar situations.

Appendix 2. ^{14}C Radionuclide Contamination

Phase I: Historical Site Assessment

A biomedical research laboratory is to be completely renovated. The occupants routinely used ^{14}C in submillicurie quantities.

The NRC strictly regulates ^{14}C use. NRC regulations require the review and approval of radioactive material procedures, as well as routine surveys of the workplace. This documentation would be a valuable resource in determining any areas of concern or potential radioactive contaminants in the laboratory. The procedure review would indicate whether the material was likely to become airborne—information useful for determining the need to evaluate exhaust ductwork. The survey documentation would identify areas of the laboratory where radioactive material had been handled and where radionuclide contamination had been found previously. Additionally, current and past lab occupants should be interviewed to determine any historical use, storage, or spills not documented in the written records.

Phase II: Characterization Assessment

It is necessary to perform surveys for both total and removable contamination. The total contamination measurements are made using a portable meter with the properly selected detector and slowly passing the detector over the surface of concern. For a low-energy beta emitter like ^{14}C, the use of a large-area gas proportional detector or a large area plastic scintillation detector would be appropriate. The removable contamination measurements are made by wipe testing the affected areas and counting the wipes in the appropriate laboratory counting equipment. Either a liquid scintillation counter or a flow-through proportional counter is used to analyze ^{14}C wipe tests.

For both types of survey, it is imperative that the detection system used is capable of identifying contamination at the level necessary to determine whether the surface is at or below the acceptable level of contamination for the radionuclide of interest. Contamination measurements are typically evaluated in terms of activity/100 cm^2, so it is necessary to ensure that the surveyed area is 100 cm^2 or that the results can be readily corrected to units of activity/100 cm^2.

The number of sample points is dependent on the expectation of contamination determined during the Phase I evaluation. If no contamination is expected, then a scoping survey consisting of sampling points selected on the professional judgment of the health physicist may be used. If contamination is expected, then a more thorough characterization survey should be performed. The characterization survey may include a reference grid for methodical measurements in addition to judgment-based measurements.

If a survey measurement is below the acceptable total or removable ^{14}C contamination criterion, the surface is suitable for unrestricted release. The value of the acceptable ^{14}C contamination criterion is potentially available in three places: *a*) the radioactive materials license; *b*) NRC guidance documents (*10*); or *c*) NRC regulations.

The typical fixed and removable values used as ^{14}C contamination criteria are 5,000 and 1,000 disintegrations per minute dpm/100 cm^2, respectively (*10*). However, the NRC recently published a license termination total ^{14}C contamination criterion of 3,700,000 dpm/100 cm^2 (*11*). The license termination criterion is not directly applicable to our laboratory renovation scenario, but it would be worth adopting through a license amendment.

Phase III: Remedial Effort

The goal in this case would be to release the structure and equipment for unrestricted use, thereby relieving any concern for radiological

oversight. The criterion provided in Phase II would be used to make this determination. Any structure or equipment not meeting release criteria requires decontamination. Any structure or equipment not meeting release criteria after decontamination is disposed as radioactive waste.

A variety of decontamination procedures exist for cleaning radioactive material areas. They can be as simple as using tape to remove dry, discrete particles, or as complicated as using abrasion (e.g., scabbling) to remove contaminated surfaces. Various techniques are readily found in the radiation safety literature [i.e., *The Health Physics and Radiological Health Handbook* (*12*)].

Phase IV: Final Status Survey

After all decontamination is completed, the MARSSIM document provides excellent guidance in performing final surveys to ensure that the release criteria have been met. Impacted areas are classified into Class 1, 2, or 3, depending on the expected severity and likelihood of contamination. A methodology is developed for determining the random sampling of the impacted areas to ensure that enough samples are collected. Appropriate statistical tests are provided to evaluate the measurement results in terms of the release criteria to ensure that the area is below the criteria prior to being released for unrestricted use.

The MARSSIM provides an outline for the material that should be included in the final status survey report. Clearly, the final project report should include the facility background used to identify the potential radioactive contaminants and impacted areas, the release criteria, instrumentation selection, survey measurement results, the statistical test(s) employed to evaluate the survey results, and the final determination.

Appendix 3. ^{3}H, ^{14}C, and ^{125}I Radionuclide Contamination

Phase I: Historical Site Assessment

^{3}H, ^{14}C, and ^{125}I are routinely used in a biomedical research laboratory for research purposes (e.g., tracer studies). They are used on benchtops, in laboratory chemical hoods, and sometimes spilled on floors or dumped in sinks. The available documents to review include the routine health physics surveys for the lab, sink disposal logs, iodination logs, and material receipt forms. The license to possess radionuclide materials may also specify what radionuclides could be used in the lab and in what quantities.

Phase II: Characterization Assessment

Evaluate likely areas where contaminants may have accumulated, such as floor surfaces near benches and hoods where the material was used. Areas to survey include benchtops, hoods, glove boxes, sinks, floor surfaces, sink drains, and waste disposal areas. It is important to gain access to all potentially contaminated surfaces, including beneath floor tiles and behind laboratory chemical hoods. These areas will be the focal point of characterization efforts to determine if there is a contamination problem. Survey techniques will include surface scanning, followed by direct measurements of surface activity (in dpm/100 cm^2), and smears.

These radionuclides are all difficult to detect with field survey instrumentation. A Geiger Mueller detector can be used to detect ^{14}C and even ^{125}I to a lesser degree (though sodium iodide detectors do better for ^{125}I). ^{3}H cannot be detected with a field instrument. Smears/wipes can be used to measure the removable activity from these contaminants using liquid scintillation counting.

It is necessary to know the acceptable release criteria for these radionuclides. If contamination is detected, the measured levels (in dpm/100 cm^2) are compared to the release criteria to evaluate what areas may need remediation. Therefore, it is essential that the measurement techniques be sensitive enough to detect surface activity at release criteria levels.

Phase III: Remedial Effort

A decontamination plan can range from simple techniques (washing and wiping surfaces down) to more elaborate approaches such as equipment removal (hoods or sink drain lines). ^{3}H is difficult to completely decontaminate because it diffuses into surfaces and offgases from these surfaces. ^{125}I is easily volatized, so contamination can be quite widespread in a lab, especially on metal surfaces where it plates out. A remedial action support survey should be performed immediately following decontamination to assess the success of remediation activities.

Phase IV: Final Status Survey

A final status survey can be planned using the MARSSIM. The same survey techniques used to characterize the contamination can be used to demonstrate that any residual radioactivity complies with release criteria (e.g., 25 millirems per year). The final status survey documentation provides a complete and unambiguous record that release criteria for these radionuclides satisfy decontamination criteria.

Appendix 4. Arsenic Contamination

Phase I: Historical Site Assessment

A decision was made in 1995 to close and sell a semiconductor research and development facility built in 1984 that comprised four stories plus a lower level. First floor included a 10,000 ft^2, class 100 cleanroom where both silicon and gallium arsenide processing was done.

The goal was to decommission to an end point that would allow the corporate real estate group to sell the building for continued use as a semiconductor facility. It was believed this would limit future liability of the current owner. All hazardous materials were to be removed, but most processing equipment would be left in place in an acceptably clean condition. Processing equipment being sold or surplused would also need to be in a clean state. The definition of clean was to be subsequently defined. Full-time air-quality monitoring systems were to be turned off as soon as possible.

Given these parameters, areas of concern for arsenic contamination were exposed surfaces of all gallium arsenide processing equipment, all accessible surfaces of equipment leaving the facility, and discarded ductwork and other materials being sent out as nonhazardous waste. Heavily contaminated ductwork was immediately classified as hazardous waste.

Phase II: Characterization Assessment

All potentially contaminated surfaces in question were sampled by wipe tests. Whatman filter paper moistened with distilled water, was used to wipe 100 cm^2 of surface. This procedure was followed by analysis for total arsenic (NIOSH method 7900) (*13*). Data were evaluated by comparison with the criteria discussed below. Surfaces that did not meet the cleanliness criteria were cleaned again and resampled.

Several potential cleanup criteria were evaluated, including industry practice, health-based criteria, toxicity characteristic leaching procedure (TCLP), and legal. An informal standard of 10–100 μg/100 cm^2 has been used in the semiconductor industry to allow release of equipment for other industrial use. This was originally based on an analogy to a California Occupational Safety and Health Administration standard for 4,4-methylene-bis-2-chloroaniline, another material considered carcinogenic (*14*). The industry practice also considered a level of less than 10 μg/100 cm^2 acceptable for all uses except as an eating surface. From a health-based perspective, a 65 μg/100 cm^2 level was derived from the drinking water standard for arsenic of 0.05 mg/L and assumptions about potential contamination of hands and resulting ingestion. The Resource Conservation and Recovery Act (RCRA) TCLP criteria for arsenic were applied to a typical piece of ductwork as if it were ground down to a sample that could be analyzed by EPA method 1311 (*15*). This yielded a maximum allowed surface contamination of

17 mg/100 cm^2 before the material would be considered hazardous waste. An outside legal opinion leaned on EPA's hazardous debris treatment standards (*16*), which defined clean as follows:

> The surface, when viewed without magnification, must be free of all visible contaminated soil and hazardous waste except the residual staining from soil and waste in cracks, crevices, and pits may be present provided that such staining…must be limited to no more than 5% of each square inch of surface area.

The decision to choose 10 µg/100 cm^2 was made because it was the most conservative criterion and met the end point goals discussed above. This was easily attainable for almost all of the surfaces after first cleaning and for most of the remainder with a second cleaning.

Phase III: Remedial Effort

Surfaces were cleaned to Phase II criteria. Cleaning of surfaces was simply done with either water or isopropanol wet wipes. All wipes joined the hazardous waste stream. HEPA-equipped vacuums were used to pick up any loose debris from the cleaning. All sampling data were kept; the spreadsheet was sorted by equipment or laboratory area. Ductwork or piping that could not be cleaned to the criteria was removed as hazardous waste.

Phase IV: Final Status Survey

A report on all of the activities in prior phases was made available to prospective buyers. The goal of leaving the facility in a condition that no longer required full-time monitoring and that was safe for normal usage as a semiconductor fabrication facility was fulfilled.

Appendix 5. Mercury Contamination in Plumbing System

Phase I: Historical Site Assessment

As part of a consolidation effort, a Federal agency decided to move certain biomedical research activities to another region. This move required personnel to vacate a laboratory building so it could be decommissioned and transferred to the General Services Administration, the leasing agent.

The future use of the building was identified during the Phase I interview process. The property owner indicated that he planned to demolish the building and construct a parking lot in its place.

Although several areas of environmental concern were identified during the interview process, the primary hazard of concern was mercury in the plumbing system. The laboratory personnel had worked extensively with products containing mercury (e.g., mercury iodide, mercury chloride) and expressed concern that trace amounts of mercury may have found its way into the plumbing system. If the pipes were contaminated with mercury, demolition workers would then be at risk of exposure. In addition, compliance with hazardous waste regulations might be compromised. To determine whether mercury was present in the plumbing system, samples were collected and analyzed for mercury during a Phase II survey.

Phase II: Characterization Assessment

To determine the sensitivity required for sample analyses, applicable Federal, state, and local regulatory standards were reviewed to identify a potential release criterion that could, if necessary, be achieved using a decontamination method. Because there were no state or local regulatory standards for the disposal of mercury-containing biomass found in plumbing systems, a decision was made to follow the guidance provided by the EPA 1992 "Technical Support Document for Land Application of Sewage Sludge" (*17*). This guidance allows for 17 ppm mercury (dry weight) in sewage sludge to be applied to the land. Providing for a conservative margin of error, a cleanup criterion of approximately 25% of the EPA guidance or 4 ppm mercury-dry weight was identified. With this criterion in mind, a sampling and analysis plan was then prepared along with a scope of work to identify the tasks to be carried out.

Because elemental mercury and many mercury compounds are heavier than water, they tend to settle at low points (e.g., sink traps and sumps) in a plumbing system. For this reason, samples were collected from 10% of the potentially contaminated sink traps. Each trap was inspected and emptied into a bucket and the contents were then set aside for TCLP hazardous waste disposal analysis. This would determine whether the contents of the plumbing system needed to be disposed as hazardous waste but would not characterize the actual plumbing system. The trap was then brushed and the sludge was collected for mercury analysis using EPA method 245.5, "Determination of Mercury in Sediment by Cold Vapor Atomic Absorption Spectrometry" (*18*). As mercury also tends to collect in the biomass that occurs on pipe surfaces [Medical Academic and Scientific Community Organization, Inc. (MASCO) study] in drain lines, samples were also collected from 10% of these areas, then analyzed for mercury content using the same EPA method 245.5. According to results of the MASCO study, this biomass acts as a food source for biological growth and accumulates mercury over time (*19*).

The sampling data were reviewed and the results of the analyses indicated that mercury contamination was present in the plumbing system at levels above the identified cleanup criterion. A remedial effort was then made to decontaminate the pipes.

Phase III: Remedial Effort

A literature search was conducted to find an effective decontamination method and appropriate procedures necessary for remediation of mercury contamination in plumbing systems. The only information found on the topic was gathered from a study conducted by the Masssachusetts Water Resources Authority (MWRA)/MASCO Hospital Mercury Workgroup under the egis of MASCO in 1996 (*19*). The goal of this study was to remove enough biomass to reduce wastewater effluent mercury concentrations to below the local standard of 1 ppb. During the study, researchers subjected plumbing samples to eight different chemical cleaning (decontamination) solutions to determine which, if any, would remove, dissolve, disperse, or eliminate mercury-containing biomass from the piping. They also tested a powerwashing procedure on infrastructure piping using a KJ-1250 Water Jetter, a portable unit designed to clear biomass, grease, and sludges out of 1 1/4–4" diameter drain lines. The results of the study indicated that the powerwashing procedure used in conjunction with trap cleaning was a safe and effective decontamination method for removing mercury-containing biomass from the plumbing system. The powerwashing and trap-cleaning procedures are available in the infrastructure report found at the MASCO website (*19*).

The powerwashing procedure with trap cleaning was selected as the decontamination method, and a decontamination plan was prepared to outline the appropriate procedures to follow during the remedial effort.

The plan was implemented and the remedial effort was carried out. The wastewater generated by the powerwashing procedure was collected and tested for mercury content using the TCLP method. Based on the TCLP results, the wastewater was disposed of as a nonhazardous waste. Cursory scrapings (samples) of the pipes were then collected for mercury analyses using a field screening method developed by Turner (*20*). The results of these analyses indicated the remedial effort was effective. A final status survey was conducted to assure that the cleanup criterion had been met.

Phase IV: Final Status Survey

Using the MARSSIM approach, a final status survey was designed so scrapings (samples) could be collected and analyzed from enough areas of the plumbing system to statistically ensure that cleanup criterion had been met.

The scrapings (samples) were collected and analyzed using the more accurate U.S. EPA method 245.5 (*18*). The results of the analyses indicated that the cleanup criterion had been met.

Appendix 6. Hazardous Substances in Hood Ductwork

Phase I: Historical Site Assessment

Ductwork that has been in service for exhausting laboratory chemical hoods has been exposed to chemical vapors, and, to a lessor degree, solids. Determining the existence and extent of specific chemical contamination is difficult. The preparation of hood-specific chemical use history is often nearly impossible. Staff turnover, hood use changes, the degree of solids handling versus gas/vapor handling, the degree of local gas scrubber utilization, and other factors contribute to this difficulty. Despite the challenges faced with each lab renovation or remediation activity, site assessment cannot be ignored. Identification of the scientific disciplines that had been assigned space served by a particular hood(s) and associated ductwork must be undertaken. For example, appreciating the differences between hood use in larger scale organic chemistry labs and use in a QA/QC lab is critical. Documented staff interviews should be conducted, which involves the use of human resource records or any other means of locating and interviewing staff members who have used the hoods or ductwork in question. Methods for generating and maintaining reasonable records of chemical use history would be useful in this analysis.

Laboratory hoods are generally designed as gas/vapor control devices, and ductwork contamination should be limited primarily to vapor condensation. The hazards associated with vapor condensate are difficult to assess. Perchlorate salt and iodinated or other radioactively labeled condensates are exceptions and are easy to assess relative to most other possible contaminants. Experience at one facility has been that most condensate will appear as a rather viscous substance that ultimately can be controlled as an occupational hazard through protective clothing measures. However, the complex mixture potential and the effects of time on what was once condensation will not permit fully accurate assessments (i.e., evaporation of the condensate to a gas, drying to a residual solid, etc.).

Despite the fact the laboratory chemical hoods are generally designed for gas and vapor containment, many are routinely used for solids handling. The amount of solids collecting in ductwork is generally limited by several factors. The hood interior is very turbulent and is not designed to capture and remove (transport) dust particles. Nonetheless, solids do get entrained in the exhaust ductwork airstream and then transported and deposited according to factors such as particle density, duct velocity, and duct geometry. To what degree the ductwork is contaminated by solids is a case-by-case determination. It is often aided by knowing the use history, combined with visual inspection (by standard duct video-imaging probes), and possible surface sampling. Urban environments may create more of a problem with higher background levels of particulates. For laboratories using metals and other solid material, the duct may be contaminated. Examples of materials that contaminate hood ducts are arsenic, berylium, and acrylamide.

The Occupational Safety and Health Administration (OSHA) construction standard (*21*) does not require that construction/demolition employees have access to material safety data sheets (MSDS) for internal ductwork contamination. In fact, MSDS are not required for wastes in general. On the other hand, in order for the proper PPE to be selected for a worker, hazards should be identified so that reasonable hazard information can be communicated.

Phase II: Characterization Assessment

Several distinct groups may face occupational or environmental exposure hazards. Demolition, remediation, and construction personnel may face potential inhalation or contact exposures while working around contaminated surfaces within the laboratory area. Waste handlers and the public may face similar potential exposures during any waste disposal effort arising from contaminated ductwork.

The analytical rigor required in characterizing and quantifying chemical surface contamination for occupational risk assessment raises the question of the value of the sampling and analytical program relative to risk of handling the ductwork. This is not to say that surface sampling does not have a place in certain work where breaching or actual ductwork removal is planned. In cases where it has been determined that extremely hazardous substances are likely to be present (e.g., carcinogens, reactives), effort should be expended in making sampling a conscious consideration. The decision to test demands a professional examination beyond the scope of this article. Interested parties are urged to read *Surface and Dermal Monitoring for Toxic Exposures* by S. Ness (*22*).

Sampling of the ductwork for waste disposal decisions at one facility is based exclusively on TCLP. TCLP is a method prescribed by EPA method 1311 (*15*) to test the toxicity of a solid waste. It is basically an extraction procedure for the solid waste and simulates the leachate coming out of the waste when it is exposed to water (precipitation, for example.) It is not known how many other facilities use this procedure for environmental waste characterization. It appears that in other solid waste decisions, TCLP is the most widely accepted. There are several other extraction procedures; values given by the others are very conservative compared to the TCLP. Other methods are the ASTM shake extraction of solid waste with water (ASTM D-3987) (*23*), extraction with HNO_3, and extraction with hot water. It is not known what criteria are used in determining if the ductwork is considered a hazardous waste. The entire description of the procedure can be found in the Federal Register and in EPA's SW-846 (physical/chemical methods for analysis of solid wastes). One standard that defines clean is the National Air Duct Cleaners Association (NADCA). The NADCA Standard 1992-01 defines clean as < 1.0 mg/m^3 surface dust as collected by a vacuuming method. The relevance of this standard to our work needs further investigation.

Phase III: Remedial Effort

TCLP is not intended to characterize ductwork as RCRA hazardous. Rather, this test is used to characterize the contents of the ductwork. If the contents are determined to be hazardous, they may present a problem to the workers handling the ductwork or to the environment when disposed.

Assessment must be made to determine if the ductwork should be disposed of in a municipal, industrial, or hazardous waste site.

The information sought in Phase I work is now useful for two coordinated parties—the safety and health advisor for the owner, and the safety and health advisor for the removal party (most generally a demolition/construction contractor). The favored approach here is to have the owner relay adequate hazard information to the contractor for consideration in prescribing methods of removal and the protective measures for employees.

If decontamination was suggested at any point, the procedure itself needs to be reviewed to ensure that it would not present greater risk to the workers assigned to decontaminating than the alternative approach of bagging and disposing.

Phase IV: Final Status Survey

Documentation of the procedures used for testing and dismantling the hood and duct systems, along with proper disposal procedures, are filed in a manner that permits future reference. Standard record keeping must be done in compliance with OSHA and EPA record-keeping requirements.

References and Notes

1. National Academy of Sciences. Prudent Practices for Handling, Storage and Disposal of Hazardous Chemicals in Laboratories. Washington, DC:National Academy of Sciences, 1995.
2. Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), 42 U.S.C. 9601 (35) (B), 1980. Available: *http://uscode.house.gov/*, see Chapter 103 CERCLA [cited 7 November 2000].
3. ASTM. Standard Practice for Environmental Site Assessments: Phase I Environmental Site Assessment Process, Philadelphia: American Society for Testing and Materials, 2000;E1527.
4. ASTM. Standard Practice for Environmental Site Assessments: Phase II Environmental Site Assessment Process. Philadelphia: American Society for Testing and Materials, 1997;E1903.
5. U.S. Environmental Protection Agency. U.S. EPA/NRC/DOE/DOD. Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM). NUREG-1575, EPA 402-R-97-016. Washington, DC:U.S. Government Printing Office, 1997.
6. Edwards R, DiBerardinis L, Galanek M, Fink R, VanSchalkwyk W, Samualson K. Procedures for decontamination and decommissioning of laboratory buildings. Chem Health Safe 6(5):4–11 (1999).
7. Rutala WA. APIC guideline for selection and use of disinfectants 1994, 1996 APIC Guidelines Committee. Am J Infect Control 24(4):313–342 (1996).
8. Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). 42 U.S.C. 9620 (120) (H), 1980, as amended 7 October 1986. Available: *http://www.uscode.house.gov* , see Chapter 103 CERCLA [cited 7 November 2000].
9. Bader M, Phillips CC, Mueller TR, Underwood WS, Whitson SD. Returning perchlorate-contaminated laboratory chemical hood systems to service, Part II: disassembly, decontamination, disposal, and analytical procedures. Appl Occup Environ Hyg 14:369–375 (1999).
10. U.S. Nuclear Regulatory Commission. Termination of operating licenses for nuclear reactors. In: Regulatory Guide 1.86. Washington, DC:NRC, 1974. Available: *http://www.serversolutions.com/decomm_sec/refs.htm* [cited August 2000].
11. U.S. Nuclear Regulatory Commission. Fed Reg 63(222):64134 (1998).
12. Shleien B, ed. The Health Physics and Radiological Health Handbook. Silver Spring, MD:Scinta, Inc., 1992.
13. National Institute for Occupational Safety and Health. NIOSH Methods 7900: Arsenic and Compounds, 4th ed. NIOSH Manual of Analytical Methods. DHHS (NIOSH) 98-119. Washington, DC:NIOSH, 1998.
14. California Code of Regulations. Title 8, Section 5215 MOCA (4,4-Methylene-Bis-Chloroaniline), 2000.
15. U.S. EPA. U.S. EPA Method 1311: Toxicity Characteristics Leaching Procedure. EPA SW-846. U.S. Environmental Protection Agency. Available from Springfield, VA:National Technical Information Service, 1992. Also available: *http://www.epa.gov/epaoswer/hazwaste/test/sw846.htm* [cited August 2000].
16. Protection of the Environment. 40 C.F.R. 268.45, Available: *http://www.access.gpo.gov/nara* [cited November 2000].
17. U.S. Environmental Protection Agency. U.S. EPA Technical Support Document for Land Application of Sewage Sludge. EPA 822/R-93-001AB. Springfield, VA:National Technical Information Service (NTIS PB3110575 and PB93110583), 1992.
18. U.S. Environmental Protection Agency. U.S. EPA Method 245.5: Determination of Mercury in Sediment by Cold Vapor Atomic Absorption Spectroscopy. Springfield, VA:National Technical Information Service (NTIS PB91231498), 1992.
19. MASCO. Infrastructure Subcommittee Maintenance Guidebook. Boston:Medical Academic and Scientific Community Organization, 1998. Also available: *http://www.masco.org/mercury* [cited August 2000].
20. Turner R, Kriger A. Field analysis of mercury in water, sediment and soil using static headspace analyses. Water Air Soil Pollut 80:1295–1304 (1995).
21. OSHA Safety and Health Regulations for Construction. 29 C.F.R. 1926.59. Available: *http://www.access.gpo.gov/nara/* [cited November 2000].
22. Ness SA. Surface and Dermal Monitoring for Toxic Exposures. New York:Van Nostrand Reinhold, 1994.
23. ASTM. Standard Test Method for Shake Extraction of Solid Waste with Water. ASTM D-3987. Philadelphia:American Society for Testing and Materials, 1999.